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Market-Enhanced Technological Integration in Favor of Widespread Bt-Cotton Use in Yangtze River Valley (China)

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Abstract

The wide diffusion of Bt-cotton in China (mainland) is well documented. It is estimated that Bt-cotton covers about 70% of the national cotton areas. Cotton is produced in three regions: Yellow River Valley, Yangtze River Valley and Xinjiang Province located in the North-West of the country. In the last province, pest pressure is low and there is little rationale for using Bt-cotton. This type of cotton is therefore mainly grown in the Yellow and Yangtze River Valleys. This paper provides evidence of the large-scale diffusion of Bt-cotton in the Yangtze River Valley (far less addressed in papers accessible to the international community). It confirms that, in this region, the specific advantages of Bt-cotton are of limited extent, if any, as already reported by Chinese scholars. This is a case of paradox which has not been reported earlier. The paper is based on official data series which have seldom been exploited, in particular data related to cotton areas distributed between the main varieties and to registration for variety marketing on a national scale. Our paper suggests two factors to explain the observed paradox. We first contend that Bt-cotton diffusion has benefited from synergy with pre-existing production techniques, namely transplanting with hybrid seeds, a phenomenon we call technological integration. This integration has also been enhanced by remarkable development of the variety and seed sectors, which has literally embedded technological integration in hybrid seeds. The concept of technological integration might be more general than in the studied case and brings into question the practice of Bt-cotton seed pricing.

Introduction

In China, GM cotton has been marketed since 1997 with Bt-cotton varieties. Today, it is estimated that Bt-cotton covers 70% of the total cotton area in the country (James, 2008), although with variations between cotton regions and distinct evolutions for hybrid and non-hybrid cultivars (Xu and Fok, in press). Cotton is mainly produced in three regions, Yellow River Valley (YeRV), Yangtze River Valley (YaRV) and North-West region (represented mainly by Xinjiang Province) where the pressure of Bt-cotton target pests is lower. Papers accessible to the international community have mainly dealt with YeRV, where Bt-cotton adoption is close to 100% because of a reduction in pesticide use and some degree of yield gain (several papers resulting from Prof. Huang Jikun's team and its US partners, and notably (Huang et al., 2002)). A similar adoption level is also considered in YaRV, but papers in a Chinese journal have reported little, if any, reduction in pesticide use or gain in profitability (Xu et al., 2004). There is a kind of paradox-widespread Bt-cotton adoption in spite of little specific gain-which is seldom reported in countries adopting Bt-cotton.

This paper provides a picture of a paradoxical adoption of Bt-cotton in YaRV and, in particular, its main constituting province, Jiangsu province. It is based on the outcome of a specific survey combined with official data seldom exploited before. It suggests two explanatory factors: technological integration and variety & seed market development. Technological integration is understood as being compatibility, if not synergy, between pre-existing and newly introduced techniques. Section 2 deals with the current situation of wide adoption of Bt-cotton in YaRV. Section 3 clarifies the phenomenon of technological integration and its interaction with variety & seed market development. Various sources of data, seldom exploited by published papers, are used here; the nature of these sources and their process methods will be described before presenting the results we have obtained.

Widespread adoption in spite of the limited degree of specific Bt-cotton advantages

The use of Bt-cotton in Jiangsu Province, or throughout the YaRV, is almost general. Little reduction in the chemical control of cotton pests is observed, or gains in profitability. This is paradoxical and contrary to most papers reporting cases of widespread adoption of Bt-cotton.

Features of almost generalized adoption of Bt-cotton

The picture of the current situation of Bt-cotton adoption in Jiangsu Province was gained from a survey conducted in

2005, complemented by a set of official data.

The survey in 2005 ("2005 survey") covered a sample of 186 cotton growers in the main four cotton producing districts, intended to determine producer practices in the 2004 and 2005 cotton growing season. Until then, in China, the conducting of surveys had to depend on the contribution of official extension services. In our case, misunderstandings with those services prevented us from completing the four-visit procedure of the survey in a satisfactory way. The data collected were not as complete as initially planned, but their indicative value remained owing to rare access to detailed data related to Chinese cotton production.

In particular, the survey was used to assess the extent of Bt-cotton adoption and ask farmers the names of the varieties they used. A register of varieties was consulted to clarify the official nature of the varieties (Bt or not, hybrid or not). The real nature was checked through the connections one of the authors had within the cotton breeding sphere, to correct a few possible "errors"[1]. A variety could be officially registered as non-Bt but marketed as Bt-cotton, through very active adverts[2].

Table 1 gives the distribution of surveyed farmers according to the four potential types of cotton varieties[3] for the 2004 and 2005 campaigns, as well as corresponding areas (though only for the 2004 campaign). It shows that 97% and 91% of farmers used Bt-cotton in 2004 and 2005 respectively. On average, 80% of farmers used hybrid cultivars. All hybrid cultivars used in 2004 integrated the Bt gene in addition, and it was almost the same in 2005. There were seldom any farmers using cultivars which were neither hybrid nor Bt-cotton. In terms of occupied areas in 2004, Bt-cotton cultivars accounted for 97% of the total cotton area, the share of hybrid cultivars was about 70%.

Table 1. Distribution of surveyed farmers according to variety types

	Number of farmers concerned and % of total (in brackets)		Area concerned (% of total)
	2004	2005	2004
NH-NBt	5 (2.9)	11 (6.0)	2.4
NH-Bt	27 (15.4)	28 (15.0)	25.7
H-NBt	0 (0)	5 (2.7)	0.0
H-Bt	143 (81.7)	142 (76.3)	71.9
Total	175 (100)	186 (100)	100.0

Note: H=hybrid; NH= non-hybrid; NBt= non-Bt;
Source: "2005 survey"

Data from the National Centre of Extension (hereafter "NCE data") complemented the picture of widespread adoption of Bt-cotton in Jiangsu. These data pertained to areas cultivated for the main cultivars of various crops. Only cultivars with areas above a threshold were recorded. The area threshold has fluctuated over the years, 10,000 mu (667 ha), 50,000 mu or 100,000 mu (6667 ha). Table 2 provides the evolution of Bt-cotton use since 1996 for four geographical zones: Jiangsu Province, YaRV[4], Hebei Province[5] and the whole of China.

The extent of Bt-cotton adoption, as well as its evolution, has varied between geographical zones. In Hebei Province, where Bt-cotton was released first, the adoption ratio has stabilized at up to 90%. In Jiangsu province, where Bt-cotton adoption began in 1999, the adoption rate is close to 80%, but mainly with hybrid cultivars. This is valid also for the whole YaRV. For the whole of China, the adoption rate has stabilized at 70%, with a 30% hybrid share after

[1] At least before 2000, a Bt-cotton variety might not be declared as such at the registration stage, so as to escape paying royalties to the Chinese Bt-gene owner and/or biosafety procedures. Among varieties whose cultivated areas where recorded up to 2007, 262 were officially not Bt-varieties, but 24 were.

[2] Typical cases are varieties called Zhong Mian 40, 42 and 43 which are extensively used by farmers. They are registered as non-Bt varieties by the National Centre of Cotton Research, but in several internet sites in China, they are described as pest resistant varieties.

[3] With two modalities for each of the two criteria (hybrid and Bt-cotton), four types of varieties can be potentially encountered.

[4] By combining the provinces of Sichuan, Hubei, Hunan, Zhejiang, Jiangxi, Jiangsu and Anhui. This is an approximation since part of the two last provinces belong to YeRV.

[5] Hebei Province is representative of YeRV where the use of Bt-cotton is the most reported in papers accessible to the international community.

some rapid growth in recent years. The use of hybrid cultivars with the Bt trait in China has seldom been reported to the international community; this is a specificity of the YaRV.

Table 2. Evolution of area shares for four variety types (% of total cotton areas)

		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Jiangsu Province	NH-NBt	100	100	97	94	93	90	65	40	12	18	13
	NH-Bt	0	0	0	0	0	0	12	22	29	19	9
	H-NBt	0	0	3	3	0	0	0	0	8	3	7
	H-Bt	0	0	0	3	7	10	23	38	51	60	71
YaRV	NH-NBt	94	88	79	77	46	43	33	23	16	8	9
	NH-Bt	0	0	0	2	12	18	11	18	16	21	8
	H-NBt	6	12	21	20	38	31	35	26	21	23	30
	H-Bt	0	0	0	1	4	8	21	34	47	48	53
Hebei Province	NH-NBt	96	77	29	10	0	5	5	2	0	0	3
	NH-Bt	0	23	71	90	95	84	86	97	100	100	92
	H-NBt	4	0	0	0	0	0	0	0	0	0	0
	H-Bt	0	0	0	0	5	11	9	1	0	0	5
China	NH-NBt	96	91	84	73	48	45	41	29	26	23	24
	NH-Bt	0	3	7	19	37	40	39	51	53	52	46
	H-NBt	4	6	9	7	12	9	9	7	5	6	7
	H-Bt	0	0	0	1	3	6	11	13	16	19	23

Note: H=hybrid; NH=non-hybrid; NBt=non-Bt;
Source: NCE data

Still substantial chemical control against pests

The "2005 survey" provided some information on the chemical control practices of 78 farmers. Farmers know how to control specific pests with specific ingredients they can mix at the time of spraying. So we were able to distinguish between "chemical controls" which would be greater in number than "chemical sprays". Table 3 shows that farmers still have to chemically control *H. armigera*, on average 4.1 times. Only one farmer claimed to have sprayed against *Pectinophora* (pink bollworm), another target pest that the Bt toxin effectively controls. The number of chemical controls against *H. armigera* was lower than that reported by Pray et al. (2002), who mainly focused on YeRV. This may indicate lower pressure for that pest in YaRV, as considered by Chinese scholars.

Table 3. Number of chemical controls of various cotton pests

	Number of replies about chemical control	Number of chemical controls			
		Average	Minimum	Maximum	std deviation
H. armigera	78	4.1	1.0	8.0	2.17
Pectinophoa g.	1	3.0	3.0	3.0	
Spodoptera litura	48	1.5	1.0	2.0	0.50
Aphis (aphids)	58	2.0	1.0	3.0	0.35
Lygus spp.	77	3.0	1.0	5.0	0.95
Red spider	78	3.2	2.0	6.0	1.03
Soil worms	29	1.0	1.0	1.0	0.00
Others	36	2.4	1.0	4.0	1.03
All pests	78	14,4	7.0	20.0	3.62

Source: 2005 survey

All farmers had to spray against red spiders (up to six times maximum). On average, bugs were controlled three times while that was not the case before using Bt-cotton. The leafeater, *Spodoptera litura*, has become a threat requiring chemical control (Li et al., 2004); this was confirmed by our survey. In total, on average, 14.4 chemical controls[6] were conducted in 2005. Target pests of the Bt-toxin (*H. armigera* and *Pectinophora*) still require up to four controls while non-Lepidopteran pests (aphids, red spiders, or *Lygus*) require more controls.

[6] It can be seen that not all the farmers applied insecticides against all pests. The sum of the average control numbers for each individual pest is consequently different from the mean of the total number of controls carried out.

Little gain in yield and profitability

The "2005 survey" provides only indicative information on the impacts of Bt-cotton in reducing pesticide use and in increasing yield, because not all types of varieties were represented in sufficient numbers to make proper comparisons. Table 4 shows the considerable differential in seed prices, mainly due to the hybrid feature and not to the Bt trait. Information on pesticide use and cost was only available for farmers growing hybrid cultivars. The Bt trait helped to reduce the number of chemical controls from 16.7 to 12.4, and to reduce pesticide costs from US$ 142/ha to 85/ha. These figures were consistent with earlier results published in China (Xu et al., 2004).

Subject to reservation given the small number of data, it turned out that there was no clear yield gain from the Bt trait. Again, this was consistent with earlier results published in China. Nevertheless, the positive impact of hybrid cultivars on yield was very clear. The same could be concluded for the impact on income.

Table 4. Production costs and income according to variety types

		Seed cost US$/ha	Growth regulator cost US$/ha	Cost fertilizer US$/ha	Number insecticide treatments	Cost insecticides US$/ha	seedcotton yield kg/ha	gross income US$/ha
Campaign concerned		2005	2004	2004 and 2005	2004 and 2005	2004 and 2005	2004	2004
H-Bt	Average (std deviation)	98.6 (21.7)	6.3 (3.7)	251.5 (38.4)	12.4 (4.4)	85.0 (33.5)	4392 (699)	2329 (286)
	Number data	109	112	59	77	77	140	140
NH-Bt	Average (std deviation)	6.9 (1.6)	4.4 (1.1)				3234 (440)	1600 (286)
	Number data	10	26				28	28
H-NBt	Average (std deviation)	84.5 (10.4)			16.7 (5.8)	141.9 (51.7)		
	Number data	3			3	3		
NH-NBt	Average (std deviation)	7.7 (0.5)	8.1 (3.8)				3459 (419)	1671 (286)
	Number data	4	2				5	5

Implementation of multi-location variety experiments in YaRV provided another valuable set of data to assess the yield differential between variety types. Table 5 presents the results for the 2000-2005 period corresponding to 1440 yield data. The increasing share of hybrid varieties is clear, as well as the yield superiority of those hybrid varieties. The Bt trait effect in terms of yield is misguiding in this table because most Bt varieties were hybrids whose yields were positively influenced by the hybrid effect. A multifactor analysis (distinguishing factors such as hybrid, year, experimental location and Bt trait) showed that the Bt effect on yield was not significant, unlike the hybrid effect.

Table 5. Seedcotton yield in the multi-location variety experiment in YaRV

		Number of data	Average	std deviation
Variety Types	NH-NBt	284	3001	789
	NH-Bt	166	3115	633
	H-NBt	303	3293	758
	H-Bt	877	3369	703
Hybrid Varieties	Yes	1085	3349**	706
	No	355	3089	699
Bt Varieties	Yes	986	3321*	692
	No	454	3208	751

On the whole, the results of our survey confirmed a paradoxical situation of the widespread adoption of Bt-cotton in spite of limited, if any, specific gain from the Bt trait; however, the effect of hybrid varieties, generally integrating the Bt trait, was high.

Widespread adoption due to technological integration and seed market development

In this section, we argue that the adoption of Bt-cotton is due to its effective integration in pre-existing cultivation techniques and that this integration was facilitated by the development of the seed sector in China.

Favourable pre-existing technological context

China ranks first in cotton production and consumption. The country has also achieved high yields through intensive use of inputs (fertilizers, pesticides, growth regulator) and sophisticated cultivation techniques (plastic mulching, elimination of vegetative branches, topping). The intensive cotton growing mode is an application of the outputs of active research which has succeeded in taking on board solutions from abroad and in developing its own original solutions. Indeed, transplanting and the release of hybrid varieties are two original solutions which pre-existed the commercial release of Bt-cotton and which have impacted on its use.

The transplanting technique was embarked upon to shorten the cotton growing cycle and prevent damage by early frost. It has been described in detail (Fok and Xu, 2007). In short, cotton seeds are sown in the nursery in a specific way, plantlets are ideal for transplanting at the four-leaf stage. Transplanting is carried out one day after harvesting winter cereal (wheat or barley) and after burning the crop residues. The transplanting technique is laborious and labour-intensive but it had been adopted by 90% of farmers at the end of the 1990s (Li et al., 2000) and has become generalised today in YaRV. However, labour requirements are proportional to planting density. The transplanting technique would have been even more attractive if planting densities could be reduced, which was eventually achieved through the commercial release of hybrid varieties.

Research on developing hybrid varieties was launched in 1956, but the commercial release of intra-specific hybrid varieties remained limited up to the mid-1990s (Table 2). Their adoption remains concentrated in YaRV, in combination with transplanting, because the planting density has been decreased from 45,000 plants/ha to 30,000 plants/ha.

Institutional change favourable to seed market development

The institutional change to promote development of the seed sector in China was elaborated from the perspective of emerging countries (Fok and Xu, in press). The status of resulting market competition has also been presented in an international perspective for all countries having adopted Bt-cotton (Xu and Fok, in press). Development of the seed sector in China has been guided by the Seed Law (SL) and the Variety Property Protection Act (VPPA) which became operational in the late 1990s. We focus here solely on the main aspects affecting the features of the variety and seed sector development.

Only varieties with clear property rights can be marketed (VPPA, article 6), but the right of breeders to integrate any protected variety (GM or not) in their breeding programme is preserved (VPPA, article 10). This latter article even permits farmers to use and to sell the seeds obtained from their own production.

The SL clearly acknowledges that breeders must be financially compensated when their varieties are marketed (Article 10). It passes responsibility to local authorities to promote the production and distribution of quality seeds, notably by setting aside specific funding to help new, either public or private organizations to emerge that are devoted to that purpose (Article 6).

It is worth noting that, prior to implementation of the new institutional framework, the Chinese Bt-gene worked on by the team of Prof. Guo Sandui (Research Centre on biotechnologies of Beijing, Chinese Academy of Agricultural Sciences), was patented in 1995. Its use was open to Chinese breeding organizations, against payment of royalties whose modalities have evolved several times (Xu and Fok, in press).

The particular institutional framework in China is responsible for wide use of farmers' seeds: 55% of farmers were using these seeds, partially or totally in 2002 and 2003 in Hebei Province (Fok et al., 2005). Nevertheless, where hybrid varieties are commonly used in combination with transplanting, no use of farmers' seeds was observed (Fok and Xu, 2007). This is an indication that the option of marketing hybrid seeds is a solution for reversing the tendency of farmers to use their own seeds to the detriment of commercial seeds. This option explains the growth in the share of hybrid cultivars, as revealed earlier in Table 2.

The growth in the share of hybrid varieties also results from the ease with which new high-yielding varieties are quickly and effectively obtained. It is enough to cross a variety with desired agronomic traits with a Bt-variety to obtain a hybrid that also keeps the Bt trait because of the dominance of the Bt gene. This trend is not hindered by the cost of accessing Bt technology, which is rather low at € 20-30,000 per variety at registration (Xu and Fok, in press). In addition, owing to market competition and farmers' attraction to novelties in China, as soon as one breeding organization proposes a hybrid cultivar integrating the Bt trait, all breeding organizations have to follow, whatever the specific advantage might be of such integration. This is sustained by the growing share of varieties combining hybrid and Bt traits, as already highlighted (Table 2).

Increased dynamism in the supply of varieties since the advent of Bt-cotton

The number of varieties being widely used has substantially increased since the application of the new institutional framework. Referring to the area data of NCE data, 372 varieties were used during the 2000-2006 period, against 199 over the 1990-1999 period (Table 6). There were 72 used during both periods, so we can see that there were about 300 new varieties being used over the recent period, implying stiffer competition, as shown in the last column of Table 6 which indicates the decrease in the theoretical average area share per variety.

Table 6. Evolution of the numbers of varieties used by farmers

	Number of varieties with recorded areas	Number of varieties with areas over 6667 ha	Total areas * (ha)	Average areas. All varieties during periods * (ha)	Average area */year (ha)
1990-1999	199	199	44 423 680	223 235	22 323
2000-2006	372	203	28 854 401	77 566	11 080

* Area thresholds for CNE recording have fluctuated between 667 and 6667 ha (or 10,000 to 100,000 mu)
Source: CNE data

The dynamism of the supply of varieties is also demonstrated by the number and diversity of breeding organizations involved. We have used the data available from the National Variety Registration Service ("NVRS data"), which gives the names and the nature of varieties, as well as the identity of the breeding organizations.

Over the 1999-2007 period for which data are available, 156 distinct organizations were involved in submitting varieties for registration with a view to marketing on a national scale (Table 7). These organizations were mainly located on provincial and district levels. Research organizations are still the most active in cotton breeding, but private companies are catching up, although they have only been emerging since 2000.

Table 7. Distribution of breeding organizations having submitted varieties for national registration

Administrative level of breeding organization headquarters	Firm	Colleges/Universities	Research Institutes	Agricultural Services	Total
County	9	1	11	1	22
District	35	1	31	1	68
Province	17	11	26	3	57
Central	2	1	6		9
Total	63	14	74	5	156

Source: NVRS data (downloaded in November 2007)

Technological integration sustained by variety market development

NVRS data confirm the evolution of variety supply towards cultivars combining both hybrid and Bt traits in YaRV where transplanting is generally adopted. When considering all breeding organizations having submitted varieties for national registration, there were in total 634 varieties submitted during the 1999-2007 period (Table 8), with an annually increasing number (113 in 2007 against 27 in 2000). The tendency to propose Bt varieties and hybrid varieties is very clear. Almost all hybrid varieties integrate the Bt trait in addition.

This tendency is furthermore clear with breeding organizations whose headquarters are located in provinces where transplanting is widely adopted.

Table 8. Evolution of the distribution of varieties submitted for national registration, according to their types

		1999	2000	2004	2007
All breeding organizations	Number of varieties submitted	9	27	73	113
	NH-NBt, %	67	37	26	13
	NH-Bt, %	0	19	41	28
	H-NBt, %	33	19	3	1
	H-Bt, %	0	26	30	58
Breeding organizations with headquarters located in YaRV	Number of varieties submitted	4	10	16	34
	NH-NBt, %	50	30	6	0
	NH-Bt, %	0	0	38	9
	H-NBt, %	50	40	12	3
	H-Bt, %	0	30	44	88

Source: NVRS
Note: NH-NBt for non-hybrid and non-Bt; H-Bt for hybrid and Bt

The development of the variety market is geared towards a combination of hybrid and Bt traits in the same varieties. Diffusion of the Bt trait benefits from the diffusion of hybrid cultivars because the value of the latter is acknowledged for its profitability in transplanting. Two levels of compatibility/synergy are indeed observed. The first pertains to the integration of a new technology (Bt trait) in an existing technology set (hybrid cultivar & transplanting). The second corresponds to the development of the variety market, enhanced by the commercial release of Bt-cotton and geared towards the combination of hybrid and Bt traits, leading to embedding of the technological integration process in seeds.

Conclusion

The rate of Bt-cotton adoption is quite high in YaRV though specific advantages, if any, are rather limited. This is a paradoxical situation which is seldom reported in countries adopting Bt-cotton. This situation is explained by the development of the variety market and by the phenomenon of technological integration.

In YaRV, Bt-cotton adoption cannot be disassociated from the use of transplanting, whose profitability is enhanced by using hybrid varieties. Any specific advantages of Bt-cotton might be of limited extent, but the global effectiveness of the whole set of technologies involved could be far more attractive.

The demonstration conducted was valid for YaRV and was made easier because of the specificity of transplanting use. This does not necessarily imply that the notion of technological integration is not pertinent elsewhere, in or outside China. In many cases, one can argue that Bt technology generally integrates itself into existing cultivating techniques requiring high levels of monetary expenditure so that the marginal cost of such integration appears small and encourages adoption of the Bt trait. If so, the loss of Bt–cotton effectiveness, as has been reported in China (Wang et al., 2008), would not necessarily imply an immediate and substantial decrease in Bt-cotton use. This is consistent with the evolution observed (Table 2).

More globally, the notion of technological integration supports the idea of continuation along the technology pathway, rather than disruption, as claimed by advocates of the "Gene Revolution" (Wu and Butz, 2004, Pingali and Raney, 2004). In terms of Bt-cotton seed pricing, it seems abusive to relate the effects observed when using Bt-cotton seeds to the Bt technology alone, rather than the whole technology set. These strong implications call for more research work in other contexts of Bt-cotton.

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